Mechanical Engineering Dissertation Defense

Personalizing Gait Adaptations: Methods in Human-Machine Interaction-based Training

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Abstract

Gait impairments resulting from traumatic injuries, neuromuscular disorders, and aging significantly reduce quality of life through inefficient locomotion patterns. Traditional physiotherapy requires intensive manual intervention, while robot-aided rehabilitation often increases dependence on assistive devices. Furthermore, the heterogeneous response to interventions across populations necessitates personalized approaches that promote user participation and procedural autonomy.

This thesis investigated two human-machine interaction methods for inducing gait adaptations in healthy participants, with implications for clinical populations. First, gait entrainment was examined through external rhythmic torque perturbations delivered via soft robotic exosuits. An initial study examining perturbation magnitude effects on lower extremity joints identified a critical magnitude threshold beyond which entrainment likelihood plateaus. A subsequent experiment demonstrated that relaxing fixed-speed constraints on a conventional treadmill using an algorithm that enabled self-paced walking significantly improved entrainment likelihood at perturbation frequencies 30% higher than natural walking cadence. Finally, a Deep Q-Network agent was developed to personalize perturbation magnitudes in healthy individuals, achieving 100% entrainment success rates at participant-specific optimal magnitudes through iterative in-situ adaptations. This personalization approach addressed limitations of previous studies that used arbitrarily selected magnitudes, often yielding inconsistent entrainment success.

In parallel, visuomotor training targeted gait symmetry through visual feedback distortion of bilateral step lengths. Combined visuomotor and sensorimotor training–induced via split-belt speed ratio distortion–demonstrated higher retention of adapted gait patterns compared to individual modalities. When comparing only display modalities, augmented reality headset yielded better retention of adapted gait patterns than conventional displays–such as monitors, showing delayed decay of training effects.

Both methods successfully influenced gait parameters including step length, step symmetry, cadence, and normalized propulsive impulse through implicit and explicit learning mechanisms. Adaptations were self-initiated, enabling organic gait modulations to achieve desired goals, without adverse biomechanical effects. These findings demonstrate the clinical potential of personalized human-machine interaction approaches for gait rehabilitation while advancing understanding of neuromuscular mechanisms governing such adaptations.

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